RESEARCH MEMORANDUM

for the

United States Air Force

AN INVESTIGATION IN THE AMES 40- BY 80-FOOT WIND TUNNEL OF A YT-56A TURBOPROP ENGINE INCORPORATING A DECOUPLER AND A CONTROLLED-FEATHERING DEVICE

By Vernon L. Rogallo, Paul F. Yaggy, and
John L. McCloud III

Ames Aeronautical Laboratory
Moffett Field, Calif.

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

WASHINGTON

Sept. 9, 1954

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

for the

United States Air Force

AN INVESTIGATION IN THE AMES 40- BY 80-FOOT WIND TUNNEL OF A YT-56A TURBOPROP ENGINE INCORPORATING A DECOUPLER AND A CONTROLLED-FEATHERING DEVICE

By Vernon L. Rogallo, Paul F. Yaggy, and
John L. McCloud III

SUMMARY

An investigation of a decoupler and a controlled-feathering device incorporated with the YT-56A turboprop engine has been made to determine the effectiveness of these devices in reducing the high negative thrust (drag) which accompanies power failure of this type of engine. Power failures were simulated by fuel cut-off, both without either device free to operate, and with each device free to operate singly. The investigation was made through an airspeed range from 50 to 230 mph.

It was found that with neither device free to operate, the drag levels realized after power failures at airspeeds above 170 mph would impose vertical tail loads higher than those allowable for the YC-130, the airplane for which the test power package was designed. These levels were reached in approximately one second.

The maximum drag realized after power failure was not appreciably altered by the use of the decoupler although the decoupler did put a limit on the duration of the peak drag.

The controlled-feathering device maintained a level of essentially zero drag after power failure.

The use of the decoupler in the YT-56A engine complicates windmilling air-starting procedures and makes it necessary to place operating restrictions on the engine to assure safe flight at low-power conditions.

INTRODUCTION

Turbo-propeller units which employ rigid coupling between propeller and compressor absorb larger amounts of power when windmilling after a power failure than do reciprocating engines. This is due to high compression of greater quantities of air in the turbo-propeller unit. This large power absorption is accompanied by a high negative thrust (drag) load. In the case of multiengine airplanes, this negative thrust results in a large amount of asymmetric thrust which could be prohibitive structurally and/or stabilitywise. Although manual feathering of the propeller would reduce the negative thrust, the time interval between power failure and the build-up of negative thrust may be so small that feathering could not be initiated before excessive loads were realized. The need for automatic safety devices with this type of turbo-propeller unit to prevent the high negative thrust on the airplane is apparent.

The Allison YT-56A turbo-propeller engine to be used on the Lockheed YC-130 cargo airplane is to incorporate two such devices. One will initiate controlled feathering of the propeller to prevent the high negative thrust following power failure. This device will mechanically sense the negative torque which accompanies the negative thrust. The controlled-feathering device will be backed up by a decoupler which separates the propeller drive from the compressor-turbine drive at higher negative-torque values.

Inasmuch as there are no known experimental data for engines employing either of these types of devices, the United States Air Force requested that an investigation be made of the devices[1] installed on a YT-56A turbo-propeller unit in the Ames 40- by 80-foot wind tunnel. Accordingly, an investigation was made to determine if these devices would prevent the rapid build-up of large drag values after power failure, which could result in angles of yaw large enough to cause structural failure of the vertical tail of the YC-130 airplane. In addition, the ability to automatically windmill air-start the engine, as well as the effects of the decoupler during landing approach conditions with high compressor bleed were investigated.

Presented in this report are typical oscillograms showing the salient characteristics (i.e., thrust (drag), engine torque, fuel pressure, turbine-inlet temperature, etc.) of the engine propeller unit during simulated power failure at various power settings and tunnel airspeeds. The oscillograms were made with (1) decoupler not free to operate, no controlled-feathering device, (2) decoupler free to operate, no controlled-feathering device, and (3) controlled-feathering device, decoupler not free to operate.

[1]A prototype controlled-feathering device which was triggered by an electronic rather than a mechanical signal was employed for this investigation.

Summary plots of portions of the data are presented to show maximum values of drag and negative torque at several airspeeds for the above three conditions, and the time required to decouple after power failure at several airspeeds for condition (2). The effects of the safety devices during windmill air-starting the engine and during operation under compressor-bleed conditions are discussed.

MODEL AND APPARATUS

Model

The model (shown in fig. 1) consisted of a production YT-56A power package mounted on a wing panel. All engine controls were operated remotely from a control room outside the test section. The unit was equipped with an air-turbine starter for which compressed air was supplied by a Palouste gas-turbine compressor mounted on the tunnel floor.

Engine.- The Allison YT-56A turbo-propeller engine has a design sea-level rating of 3,750 equivalent shaft horsepower at 13,820 rpm. The engine's 14-stage axial-flow compressor is directly connected to its 4-stage turbine and to the propeller through the decoupler and a 12.5:1 reduction gear assembly. The engine is also equipped with an electronic torquemeter which indicates the torque transmitted through the connecting shaft from the compressor to the reduction gear box. The location of the torquemeter is shown in figure 2.

Propeller.- A three-blade Curtiss Electric turbo-propeller designated Curtiss model C-634S-E was used in this investigation. The propeller was 15 feet in diameter with hollow steel blades, Curtiss design number 862-2C4-0.

Control.- The engine-propeller combination is controlled by a power lever movable through a 90° quadrant. Power-lever position was used as a prime variable in establishing the test conditions of this investigation. The quadrant is divided into a "beta range" from 0° to 34°, and a "flight range" from 34° to 90°. The 34° position is termed "flight idle." In the beta range, the propeller-blade angle is set by a mechanical linkage to the power lever and this range is used for ground operations including reverse thrust. In the flight range the propeller-blade angle is controlled by the propeller governor.

Safety devices.- The decoupler is an integral part of the propeller drive of the YT-56A engine. Its function is to separate mechanically the compressor-turbine section from the propeller reduction gear when a preset negative torque (approximately -250 ft-lb) is exceeded. As shown in the schematic diagram of figure 2, it is basically a helical splined coupling which is spring loaded by disk springs. The preset negative-torque value may be changed by the adjustable spacer. Decoupler action initiates a complete feather shutdown of the engine by a cam which triggers the appropriate electric circuitry. For the purposes of this test the decoupler was made not free to operate by the adjustment of the spacer in the decoupler unit.

The controlled-feathering system tested in this investigation utilized the torquemeter installed on the engine as its sensing element and its action was to energize the propeller-feathering circuit when the torquemeter signal indicated a preset value of negative torque (approximately -70 ft-lb) was being exceeded. The feathering circuit remained energized until the torque subsided below the preset limit. When the preset negative torque was again exceeded the cycle was repeated.

Apparatus

Instrumentation.- Remote indicating instruments in the control room provided the means for monitoring engine performance during this investigation. An 18-channel Consolidated oscillograph was used to record the data during the transient conditions. The items recorded and the sensing devices employed are listed in the following table:

Channel no.	Item recorded	Sensing device	Cause of upward trace deflection
1	Rolling moment	Strain-gaged beam	Roll to right
2	Thrust (drag)	Strain-gaged beam	Increasing thrust
3	Fuel pressure	Pressure transducer	Increasing fuel pressure
4	Turbine-inlet temperature	Thermocouple	Decreasing temperature
5	Decouple signal	Relay	Discontinuous trace at decouple
6	Engine rpm	d-c voltage generator	Increasing rpm
7	Propeller rpm	d-c voltage generator	Increasing rpm
8	Engine torque	Allison torquemeter	Increasing torque
9	Propeller-blade angle	Helipot	Increasing blade angle
10	Power-lever position	Slide-wire resistor	Increasing angle
11	Propeller position (controlled feathering only)	Coil and magnet	One propeller revolution
14	Support-strut deflection	Slide-wire resistor	Strut deflected downstream
15	Free-stream dynamic pressure	Pressure transducer	Decreasing dynamic pressure
16	Model longitudinal acceleration (controlled feathering only)	Linear accelerometer	Accelerating upstream
17	Dynamic pressure behind propeller (decoupler inoperative only)	Pressure transducer	Decreasing dynamic pressure

The rolling-moment and thrust (drag) variations were measured by strain-gaged beams which were an integral part of the model and restrained the model at the strut attaching points. The model support-strut deflection was measured relative to the support-strut fairing to indicate the dynamic response of the support system to the impressed forces resulting from abrupt power changes. The linear accelerometer was added to the support post on the wing to show the phase of the model motion relative to the indicated thrust (drag) and support-strut deflection. The dynamic pressure behind the propeller was recorded by means of a pressure rake connected to a transducer and was used to show the relation of changes in slipstream momentum to thrust (drag) changes as indicated by the strain-gaged beams.

Items 1 through 10 in the above table were supplied with the model. The remaining items were added during the tests.

Accuracy.- Dynamic-response surveys were made which showed that the model and supporting structure had resonant frequencies in the longitudinal (streamwise) direction of 2.25 and 3.50 cps with magnification factors of six and three, respectively. It was apparent from the traces of channels 2, 14, and 16 that during some of the transient conditions investigated (particularly the controlled-feathering tests) these frequencies were excited in the support system. Although this phenomenon precluded determination of the exact variation with time of the thrust, the values determinable from the records were sufficiently accurate for purposes of this test.

A filter in the propeller-blade-angle circuit to reduce the "hash level" in the trace proved to be of such a nature as to preclude the determination of blade-angle changes with time.

TEST CONDITIONS

To investigate the effects of the safety devices on the variation of thrust (drag) with time after power failure, engine failures were simulated by fuel cut-off at the conditions given below.

Decoupler	Controlled-feathering device	Wind-tunnel airspeed, mph (approx.)	Power-lever setting
Not free to operate	no	50,100,150,200,230	34°,46°,58°,FT[2]
Free to operate	no	50,100,150,200,230	34°,58°,FT
Not free to operate	yes	150,200,230	FT

[2]The full-temperature (FT) power-lever position corresponds to 900° F turbine-inlet temperature (approx. 3,250 horsepower) the maximum recommended by the engine manufacturer.

The ability to automatically windmill air-start the engine was investigated by attempting windmilling air-starts at 100, 150, 180, 200, and 230 mph with the decoupler both not free and free to operate.

Tests were made to determine whether the reductions in engine torque due to the use of compressor bleed and/or the rate of power-lever motion would cause the decoupler to operate inadvertently.

RESULTS AND DISCUSSION

Simulated Power Failure

To evaluate fully the effectiveness of the safety devices in the case of power-plant failure, an extensive analysis would be required of the directional-response characteristics of an airplane to the drag load induced. However, for the preliminary comparison made herein, drag values alone are considered and certain significant drag values have been selected in this regard. These significant drag values are shown in illustrative time histories of thrust and drag presented in figure 3. For the condition where the safety devices were not free to operate (fig. 3(a)) the drag value selected is the steady value following fuel cut-off. For the condition with the decoupler free to operate, the peak value has been chosen as the significant drag value. For the condition with the controlled-feathering device, the average drag level following fuel cut-off rather than a peak value has been considered because the dynamic-response characteristics of the support system caused a false indication of the magnitude of oscillating drag.

Typical oscillograms are shown in figures 4, 5, and 6 to illustrate the actual variation with time of the effects of simulated power failure. For clarity, only the pertinent variables have been labeled. From figure 5(a) it is seen that after a simulated power failure (indicated by fuel pressure drop) with the safety devices not free to operate, as much as 8,490 pounds of drag was developed by the windmilling propeller in approximately one second, a considerably shorter interval than a pilot's expected reaction time. From figures 4(b), 5(b), and 6(a), it is seen that with the decoupler free to operate, a large drag build-up, having a peak value as high as 9,450 pounds in the case shown in figure 5(b), occurred. The decoupler action, however, did limit duration of peak drag as may be noted. Figures 4(c), 5(c), and 6(b) show that the controlled-feathering device prevented a large drag build-up from occurring after the simulated power failures. For the cases shown, the maximum drag (average value as noted above) was but 1,375 pounds after fuel cut-off as may be noted in figure 6(b).

Again, it is pointed out that the frequency of indicated drag variation in figures 4(c), 5(c), and 6(b) is approximately the resonant frequency of the model support system; hence, the amplitudes of drag variation shown are probably greater than actually existed.

Summary plots of data from the tests are shown in figures 7, 8, and 9. Figures 7 and 8 show the net drag (indicated drag minus drag of model without propeller) of the turbo-propeller unit and torque absorbed by the unit after fuel cut-off for several airspeeds. For the conditions in which the decoupler is free to operate, the drag values shown are the net peak values and the torque values are the torques immediately before decoupling.[3] Drag and torque values shown for the controlled-feathering condition are the average levels reached after the fuel cut-off.

From figure 7, it is seen that at airspeeds of about 150 mph with the decoupler free to operate, the maximum drag value prior to decoupling was of the same magnitude as that with the decoupler not free to operate. It is also seen that at about 200 mph and above the maximum drag value prior to decoupling was, in general, slightly less than that with the decoupler not free to operate. The controlled-feathering system is seen to have prevented a large drag build-up after fuel cut-off, the average drag level being essentially zero.

Also shown in figure 7 is a curve representing, according to the contractor, the maximum allowable drag value at the outboard nacelle of the Lockheed YC-130 airplane. As noted, one portion of the curve represents the limit for rudder control to hold zero yaw and the other the structural limit of the vertical tail. The latter is based on a dynamic analysis with the assumption that the maximum drag is applied instantaneously and continues at this level. The values are computed for an outboard power-plant failure at sea-level conditions with the remaining three engines operating at 3,750 horsepower. It can be seen that drag values above the maximum allowable were realized before decoupling occurred. However, the drag is not applied instantaneously and continuously (see figs. 4, 5, and 6), hence the structural loads that determined this maximum allowable drag may not be realized.

As stated previously, the decoupler was designed to operate at a constant value of negative torque. Although it was not possible to predict this torque value, it was expected to be within the range of -220 to -330 foot-pounds as shown in figure 8. It is seen that for the conditions investigated, the decoupler did not operate at a constant value but at torque values which increased with increasing airspeeds.

---

[3]Following decoupler action, the torque and drag subsided to the levels of the feathered-propeller condition.

The decoupling torque values are seen to be about the same as the maximum torque values realized with the decoupler not free to operate. In contrast, the electronic controlled-feathering device maintained a constant level of torque of about 70 foot-pounds independent of airspeed.

Figure 9 shows the time interval between power failure (fuel cut-off) and decoupler action as a function of airspeed. The numbers beside the symbols designate the chronological order of these decouplings. From this figure, it is seen that this time interval is reduced with (a) increasing airspeed, (b) decreased power-lever setting prior to fuel cut-off, and (c) increasing number of prior decouplings.

Windmilling Air-starts

It was desirable that it be possible to windmill air-start the power plant in a consistent manner from a feathered condition, without the need for dexterous manipulation of related controls. Any overspeeding during air-starts should not exceed the rotational-speed limits prescribed by the engine and propeller manufacturers. "Automatic" air-starts (i.e., with one setting of engine controls) were attempted at several airspeeds. These generally resulted in an overspeed condition above the "maximum permissible," so that the propeller was feathered to prevent damage. However, by proper, simple maniuplation of the engine controls, it was possible to windmill air-start the engine at all airspeeds with the decoupler not free to operate.

Use of the decoupler introduces the possibility of decoupling during windmill air-starting of the engine. If the torque being absorbed by the unit exceeds the decoupling torque, a decouple will occur which will initiate a "feather shutdown." During automatic air-starting the engine accelerated at a high rate and, as the rotational speed approached the design speed, the fuel flow was automatically reduced to prevent engine overspeeding. This reduction of fuel flow reduced the torque in the propeller drive below that for decoupling and a decouple and feather shutdown occurred. However, again by proper manipulation of the engine controls, it was possible to reduce the acceleration of engine speed to avoid the fuel-flow reduction and attendant decoupling. Several successful "nonautomatic" air-starts were made in this manner at speeds up to 200 mph. No air-starts were attempted with the controlled-feathering device.

Effects of Power-Lever Motion on Decoupler Action

Inasmuch as it is desirable to operate the engine at low, even negative-torque values during landing conditions it was necessary to determine if the reduction in torque through the propeller drive, caused by power-lever motions or settings with zero and maximum compressor bleed, would initiate decoupling. At approximately 230 mph with zero and maximum compressor bleeds, no decouplings occurred for all power-lever settings in the flight range. Several moderate and rapid power-lever motions were made at this airspeed with zero and maximum compressor bleeds, which did not initiate decoupling. In one instance, however, with full bleed a decoupling occurred after the power lever had been moved rapidly from full temperature to flight idle. Previous tests duplicating this motion did not produce decoupling, which indicates a marginal condition.

Although provisions are to be incorporated in the YC-130 airplane to prevent inadvertent movement of the power lever into the beta range, it is possible that during landing the engine will be operated in this range. Therefore, it was advisable to determine if power-lever motions in the beta range would initiate decoupling. At 80 and 150 mph, zero and maximum-bleed conditions, power-lever motions through the full beta range (including reverse thrust setting) did not cause decouplings. At 80 mph, both moderate and rapid power-lever motions were made; at 150 mph only moderate motions were made. Moderate rate of motion of the power lever from flight idle (34°) to ground idle (approximately 17°) with zero and maximum bleed did not cause decouplings at speeds up to 160 mph. At 170 mph and 1-percent bleed and at 190 mph and no bleed, decouplings occurred following moderate rate of motion of the power lever from flight idle to ground idle.

These decouplings indicate that operating restrictions must be made to assure safe flight during low-power conditions.

Physical Condition of Decoupler

It was anticipated before the investigation that the decoupler might be of the nature of a safety fuse and that after one decoupling, sufficient damage would result to require its replacement - a task requiring considerable time and effort. It was feared that failure of the splines might occur or that burrs might form on the splines which would prevent recoupling. However, it was found that this did not occur and the decoupler acted more as a self-resetting circuit breaker.

In all, 28 decouplings occurred during this investigation. After six decouplings, the decoupler was inspected and magnafluxed and found to be in excellent condition. After 28 decouplings, the decoupler was found to be in good condition with only a small amount of wear evident. No difficulties were experienced in restarting the engine after the feather shutdowns which were initiated by decoupler action.

CONCLUSIONS

On the basis of the data obtained during the investigation of the YT-56A turbo-propeller unit, the following conclusions are drawn:

1. With the safety devices not free to operate, the drag levels realized after simulated power failures at speeds of 170 mph and above were above the allowable limits for the YC-130 and occurred in a time interval of approximately one second subsequent to the failure.

2. This maximum drag realized after simulated power failure was not appreciably altered by decoupler operation when the decoupler was free to operate.

3. The decoupler did put a limitation on the duration of peak drag.

4. With the controlled-feathering device, a level of essentially zero drag was maintained after simulated power failure.

5. With the decoupler free to operate, the magnitude of torque absorbed into the engine immediately prior to decoupling increased with tunnel airspeed and was about the same as the torque absorbed after simulated power failure when the decoupler was not free to operate.

6. The use of the decoupler in the YT-56A complicates windmilling air-starting of the engine.

7. Some restrictions of power-lever motion or compressor bleed to avoid decouplings will have to be made for operation of the engine under conditions which might possibly be encountered during landings.

8. After 28 decouplings, the decoupler was found to be in good condition and the engine could be restarted after each decoupling without difficulty.

Ames Aeronautical Laboratory
National Advisory Committee for Aeronautics
Moffett Field, Calif., Sept. 9, 1954

Vernon L Rogallo
Vernon L. Rogallo
Aeronautical Research Scientist

Paul F. Yaggy
Paul F. Yaggy
Aeronautical Engineer

John L. McCloud III
John L. McCloud III
Aeronautical Research Scientist

Approved: Harry J. Goett
Harry J. Goett
Chief of Full-Scale and Flight Research Division

FIGURE LEGENDS

Figure 1.- The model mounted in the Ames 40- by 80-foot wind tunnel.

Figure 2.- Schematic representation of the decoupler.

Figure 3.- Schematic representation of the variation of thrust (drag) with time for the three test conditions. (a) Decoupler not free to operate, no controlled-feathering device. (b) Decoupler free to operate, no controlled-feathering device. (c) Controlled-feathering device, decoupler not free to operate.

Figure 4.- Typical oscillograms for simulated power failure; airspeed = 150 mph, power-lever setting = full temperature (900° F).
(a) Decoupler not free to operate, no controlled-feathering device.
(b) Decoupler free to operate, no controlled-feathering device.
(c) Controlled-feathering device, decoupler not free to operate.

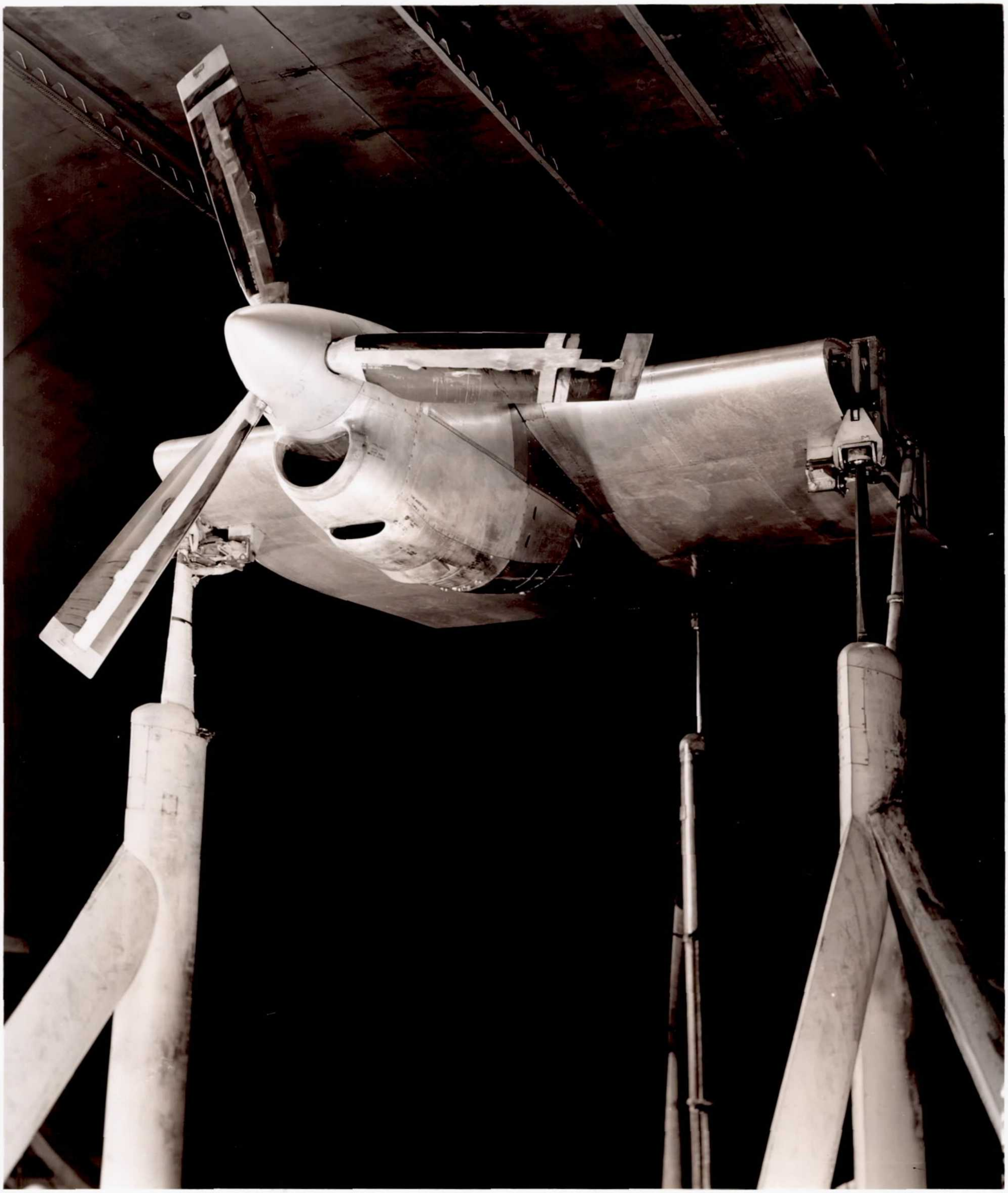
Figure 5.- Typical oscillograms for simulated power failure; airspeed = 200 mph, power-lever setting = full temperature (900° F).
(a) Decoupler not free to operate, no controlled-feathering device.
(b) Decoupler free to operate, no controlled-feathering device.
(c) Controlled-feathering device, decoupler not free to operate.

Figure 6.- Typical oscillograms for simulated power failure; airspeed = 230 mph, power-lever setting = full temperature (900° F).
(a) Decoupler free to operate, no controlled-feathering device.
(b) Controlled-feathering device, decoupler not free to operate.

Figure 7.- Net drag of the YT-56A turbo-propeller unit after fuel cut-off.

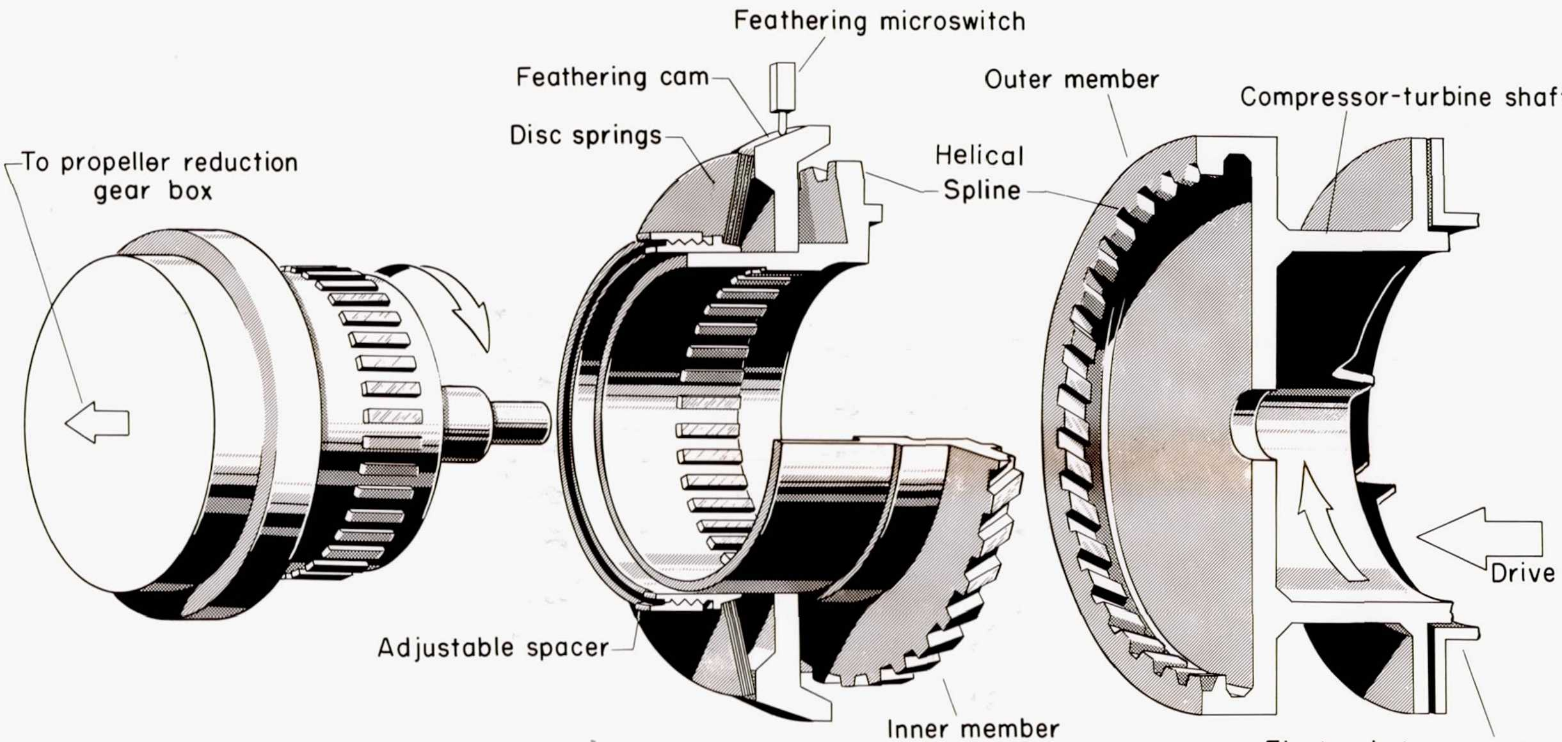
Figure 8.- Negative torque of the YT-56A turbo-propeller unit after fuel cut-off.

Figure 9.- Time to decouple after fuel cut-off; YT-56A turbo-propeller unit.



A-18957

Figure 1.- The model mounted in the Ames 40- by 80-foot wind tunnel.



Note: Rotations are shown for power transmission from engine.

A-19615

Figure 2.- Schematic representation of the decoupler.

CONFIDENTIAL

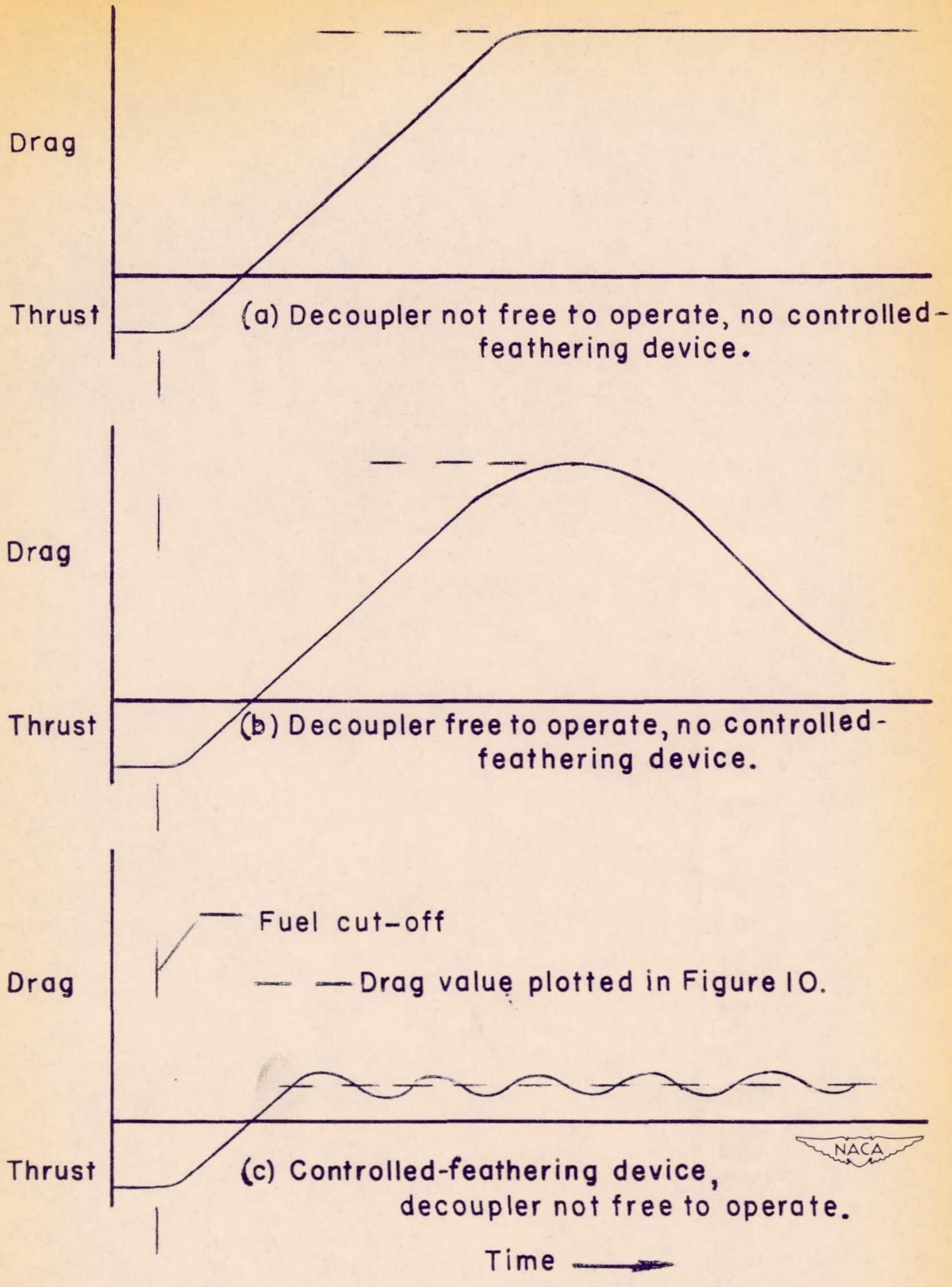


Figure 3.— Schematic representation of the variation of thrust (drag) with time for the three test conditions.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS
AMES AERONAUTICAL LABORATORY
MOFFETT FIELD, CALIF.

CONFIDENTIAL

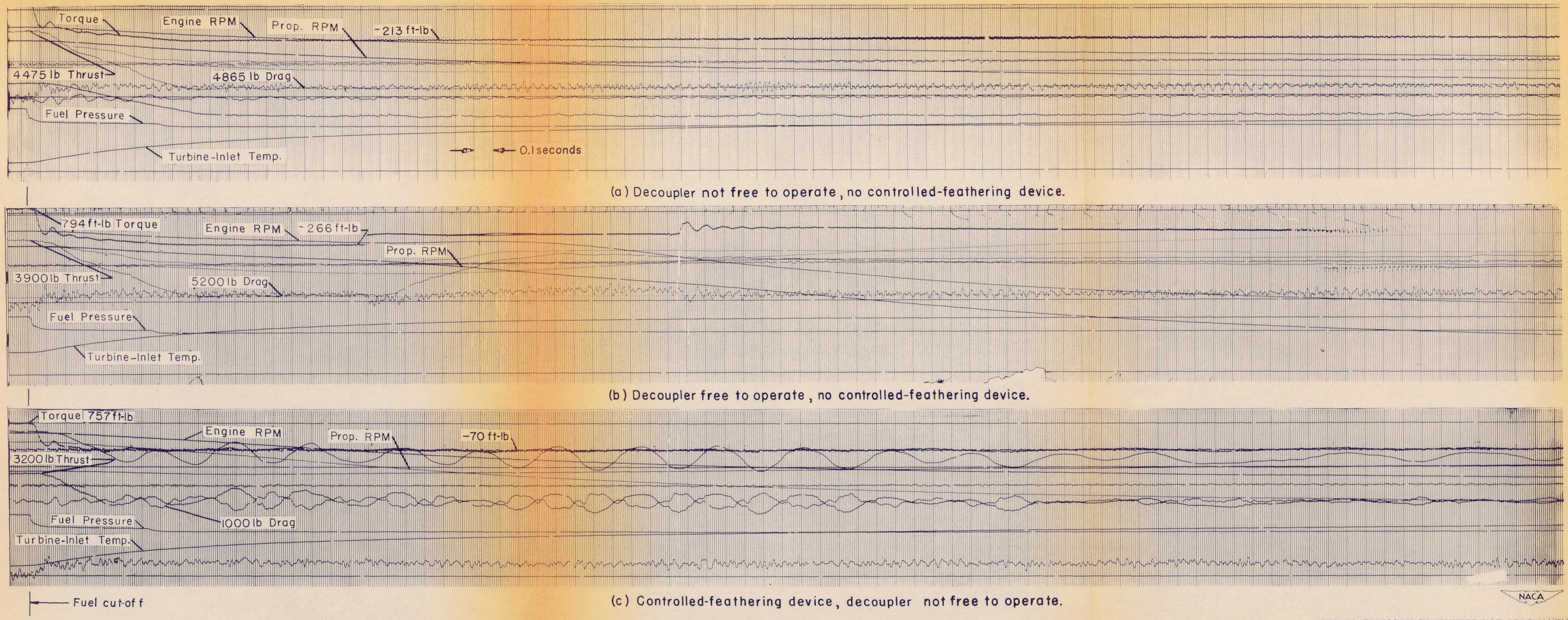
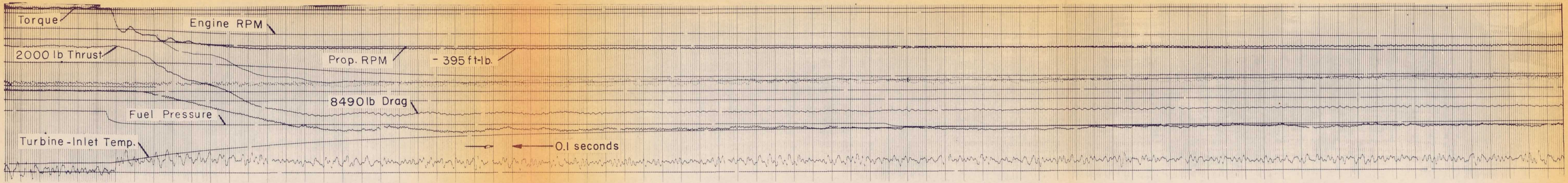


Figure 4.- Typical oscillograms for simulated power failure; airspeed = 150 mph, power-lever setting = Full Temperature (900°F).

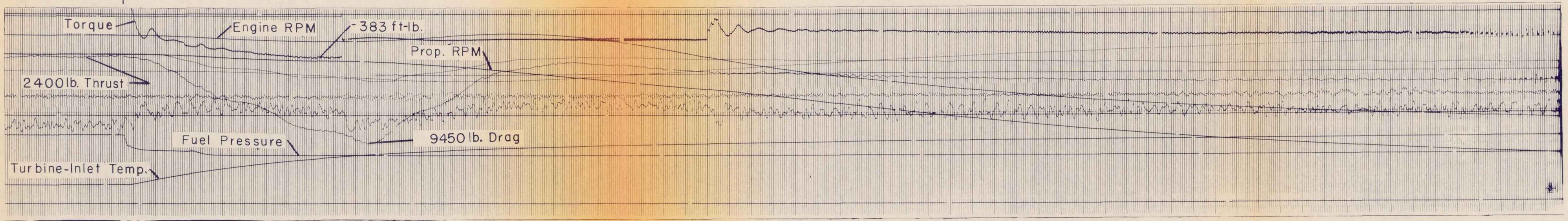
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS
AMES AERONAUTICAL LABORATORY
MOFFETT FIELD, CALIF.

CONFIDENTIAL

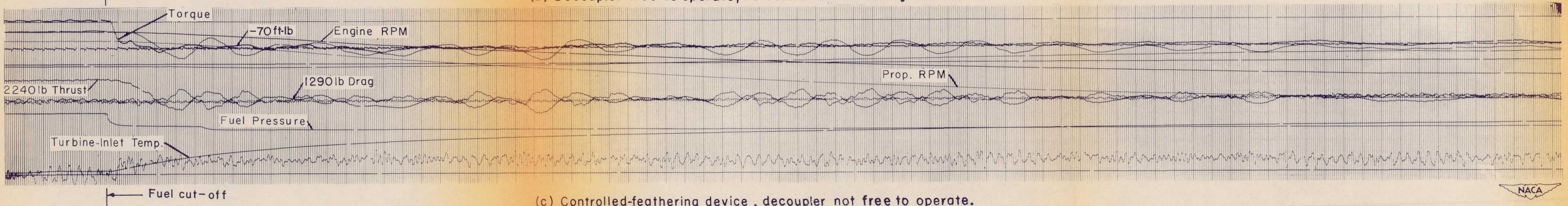
CONFIDENTIAL



(a) Decoupler not free to operate, no controlled-feathering device.



(b) Decoupler free to operate, no controlled-feathering device.

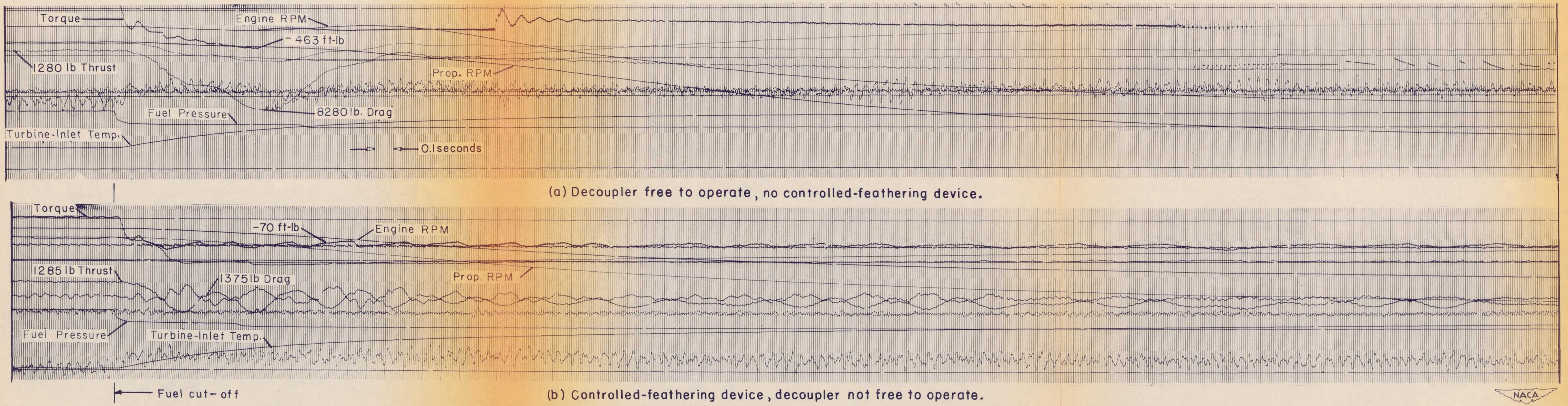


(c) Controlled-feathering device, decoupler not free to operate.

Figure 5.- Typical oscillograms for simulated power failure; airspeed = 200 mph, power-lever setting = Full Temperature (900°F).

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS
AMES AERONAUTICAL LABORATORY
MOFFETT FIELD, CALIF.

CONFIDENTIAL



(a) Decoupler free to operate, no controlled-feathering device.

(b) Controlled-feathering device, decoupler not free to operate.

Figure 6.- Typical oscillograms for simulated power failure; airspeed = 230 mph, power-lever setting = Full Temperature (900°F).

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS
AMES AERONAUTICAL LABORATORY
MOFFETT FIELD, CALIF.

CONFIDENTIAL

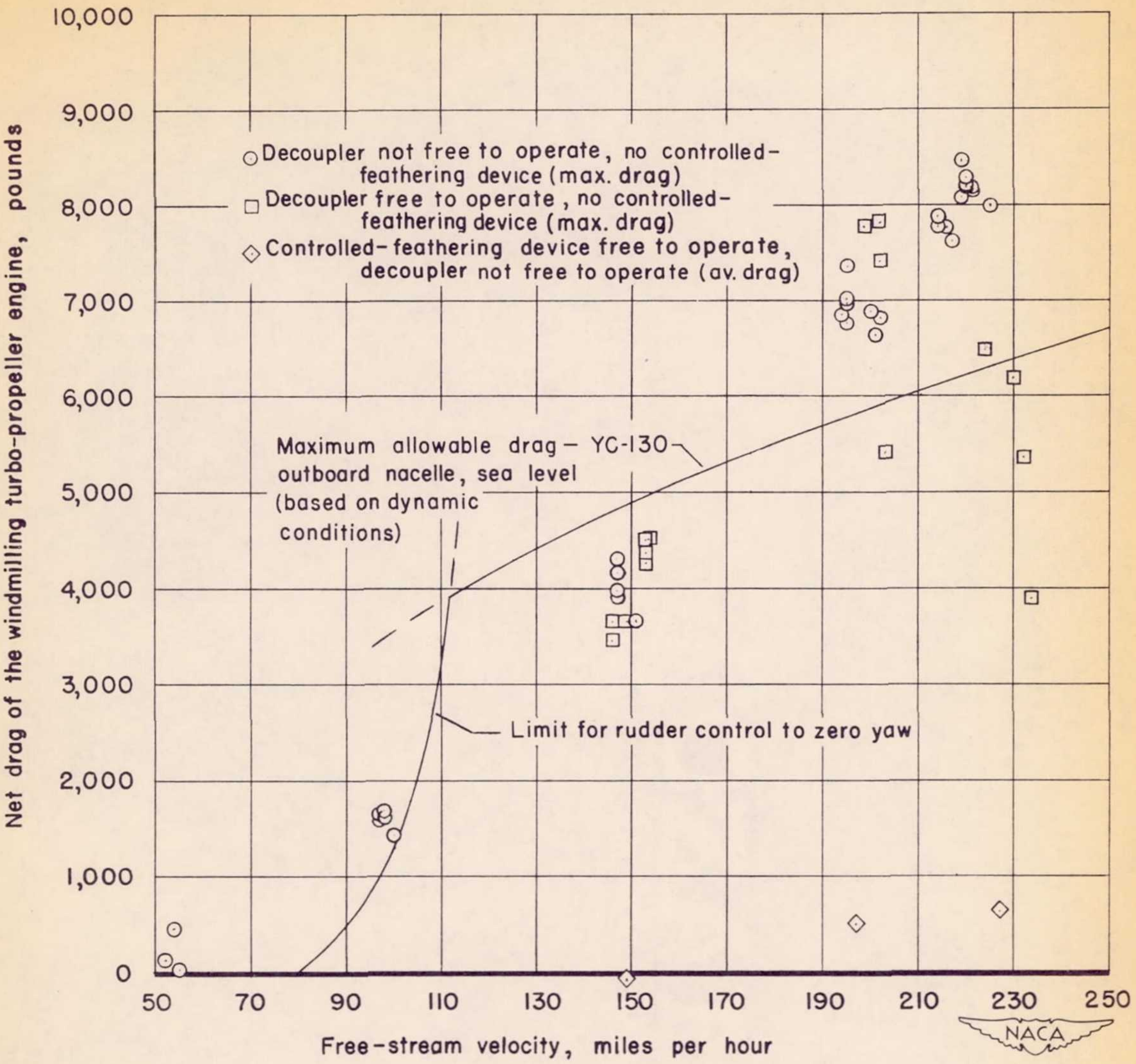


Figure 7.— Net drag of the YT-56A turbo-propeller unit after fuel cut-off.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS
AMES AERONAUTICAL LABORATORY
MOFFETT FIELD, CALIF.

CONFIDENTIAL

CONFIDENTIAL

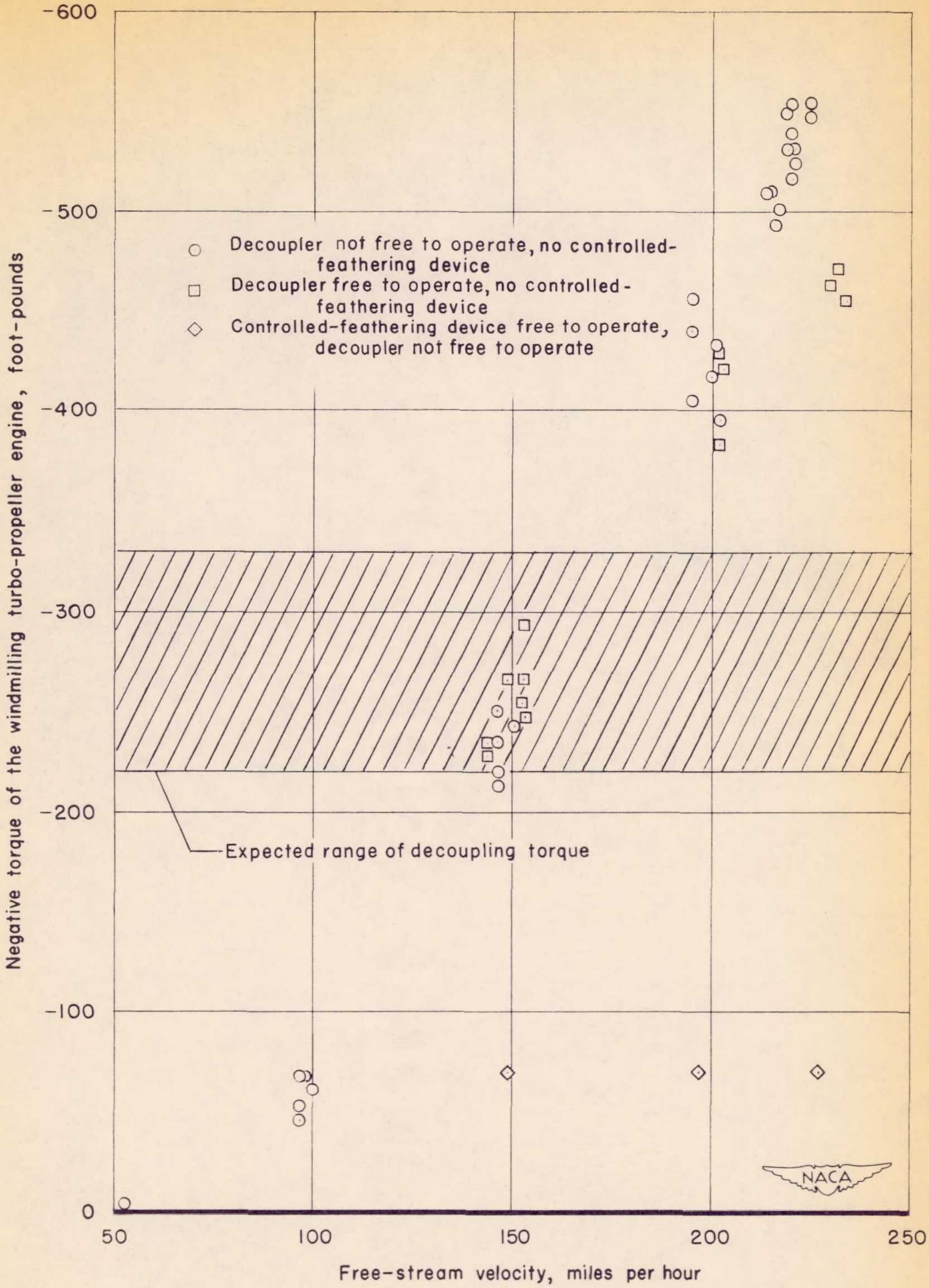


Figure 8.— Negative torque of the YT-56A turbo-propeller unit after fuel cut-off.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS
AMES AERONAUTICAL LABORATORY
MOFFETT FIELD, CALIF.

CONFIDENTIAL

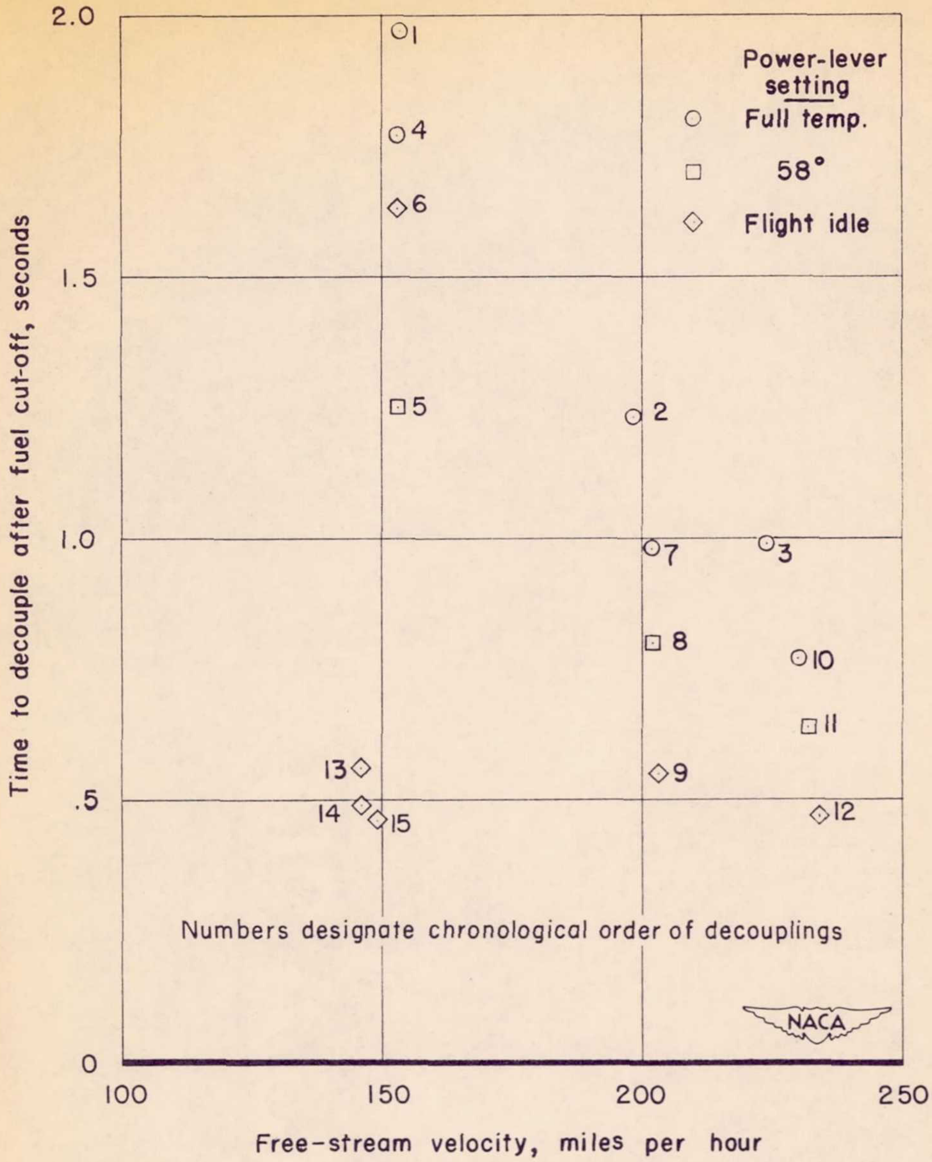


Figure 9.– Time to decouple after fuel cut-off; YT-56A turbo-propeller unit.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS
AMES AERONAUTICAL LABORATORY
MOFFETT FIELD, CALIF.